How Do Oil Prices, Macroeconomic Factors and Policies Affect the Market for Renewable Energy?

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Abstract

The aim of this study is to determine the nature of any relationship between renewable energy investment, oil prices, GDP and the interest rate, using a time series approach. We concentrate on three countries with different relationships with the renewable energy sector, with Norway and the UK being oil-exporters for most of the sample and the USA an importer. Following estimation using a VAR model, the results provide evidence of considerable heterogeneity across the countries, with the USA and Norway having a strong relationship between oil prices and renewable energy and the UK no relationship. These results reflect the fact that the USA is predominantly an oil-importer during most of this sample and supports renewable energy relatively less than the other countries, so changes to renewable energy investment reflect other factors in the market such as the price of substitutes to a greater extent than countries where renewable energy receives more government support. Similarly with Norway, where due to its market orientated approach, there is some evidence of the macroeconomy affecting the renewable energy market. The main policy implications from this study are that in countries where there is little support for the renewable energy sector, investment will be more dependent on macroeconomic aspects as well as substitutes such as oil, therefore the authorities will need to potentially increase financial support when oil prices are low or when the economy is in a downturn to ensure investment in RE continues at a constant level.

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Key Words: Renewable energy, VAR, Oil price, government policy

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1. Introduction

As concerns for the international environment grow, the international community needs to increase investment into the renewable energy (RE) sector by approximately $130bn over the next fifteen years. This is to ensure that carbon dioxide emissions peak in 2020 and global warming remains below 2°C (See IEA, 2015[1]), which is the generally accepted figure that, if broken, would push global warming to beyond acceptable limits. This means that investment into RE needs to increase rapidly, but it is less clear what will facilitate this increase in RE investment. The main factor considered here relates to whether the oil prices significantly affect the investment in and production of RE. The price of oil has recently fallen by over 60%, from highs of $107 in June 2014 to $40 in November 2015. This has created substantial debate on the potential effects it will have on investment in RE. Clearly, there is no consensus on the effects that oil prices have on renewable investment, as it depends on the extent to which oil price changes encourage investment in RE, so if the oil price increases from its current lows, as many analysts are predicting, what, if any, will be the impact of this rise be on RE investment.

Following recent international agreements over the need to reduce greenhouse gases, such as the G8 statement that it aims to cut emissions by 50% before 2050, the means of achieving these cuts is becoming ever more important. One of the most commonly used policies has involved the use of RE production as a substitute for fossil fuels. As international and European Union (EU) targets for reducing carbon dioxide emissions have become more important, so governments across the world have sought to expand the production of energy from RE sources through the use mainly of subsidies and indirectly through additional taxation on fossil fuels. As a result, government intervention in the RE market has been the dominant factor in determining RE investment over the majority of the analysis period. Because government intervention in this market is declining, due to the increasing competitiveness of RE technologies, and the degree of substitution between RE and oil is increasing, the conclusions from this study suggest that the relationship between RE and its substitutes will become more significant and robust in some countries.

There are six main original contributions of this paper to the analysis of the RE sector and which seek to fill a gap in the literature on RE policies and the development of future RE resources. Firstly, we introduce a methodology and modelling framework which captures (*a)* the individual contrasting characteristics of three distinct markets for RE by using time series data, (*b)* the interaction between oil prices and RE in a time series framework including for the first time generalised impulse response functions as well as the more conventional Granger-causality tests and (*c)* the dynamic nature of this interaction in the context of the main macroeconomic variables including national output and interest rates. Furthermore the results provide evidence that (*d)* testing for the relationship in both the long and short run suggests a short but not a long-run relationship, (*e)* using nominal and real oil prices indicates that the results are robust to either measure of oil prices. Whilst (*f*) analysing the impact of national policies on the RE markets with respect to the relationship between oil prices and RE markets provides evidence of substantial differences across these countries depending on whether they are exporters or importers of oil and also levels of support for the RE sector. Overall our aim is to demonstrate that the relationship between oil prices and renewable energy needs to be explicitly analysed on a country by country basis, due to the inherent heterogeneities within countries in terms of RE policies and natural resources, as already acknowledged in this literature. Specifically we have used annual time-series data for Norway, the UK and the USA from 1960 to 2015 and a number of techniques that haven’t been applied to this area of the literature before.

Most of the literature relating RE to oil prices and the macroeconomy, has focused on how government policy can be used to encourage RE investment, since historically RE investment has not been able to compete openly with traditional fossil fuels in terms of cost, except in Norway. [2] has examined this relationship and the effect that reducing renewable costs may have, although, they noted how hard it is to generalise the costs of RE, since it varies from location to location, and will include either costs or savings not usually experienced by traditional energy production, such as the increased costs from storing electricity, to the fact that solar energy is often installed at the point of the electricity use, so offsetting transportation and infrastructure costs. A common theme across this area of literature is that a major factor preventing investment into RE is the uncertainty over the future returns it will provide.

Whilst there is a shortage of studies linking investment in RE to oil prices using time series approaches and data, the most closely related study is by [3], but unlike this study used a panel model of RE consumption and included GDP as well as oil prices. In general, the previous literature has concentrated on RE consumption and panel data models due to the availability of suitable data. [3] found that real per capita GDP and per capita CO_2 emissions were the main long-term drivers of consumption of RE, whilst changes in oil prices had a weak negative relationship. Using G7 data, they found heterogeneity across the countries studied, with movements back towards equilibrium following a shock taking between a year and seven years. There is a large body of literature analysing the specific relationship between RE consumption and GDP growth (see [4]) which is indirectly relevant to this study, including [5], [6] and [7] who also use a panel data model along with cointegration and Granger causality tests to analyse the relationship between RE consumption, GDP, investment and the labour force. They find evidence of a long-run equilibrium and bi-directional Granger causality between RE consumption and GDP growth in OECD Countries, Eurasia and Central America. In a relate area of the literature, [8] showed that there existed a relationship between the stock prices of clean-energy stocks and oil prices, with movements in oil prices Granger causing the stock prices of the clean energy companies, which were also affected by movements in technology stocks and the interest rate. A further area in the literature analyses the relationship between RE and non-renewable energy markets (NRE), such as [9]. A final area of the relevant literature relates to the relationship specifically between oil prices, output and interest rates, such as [10] who found that both output and interest rates are significantly affected by oil price shocks.

Overall there are not many studies concentrating on the specific relationship between the RE sector and oil prices, particularly using a time series empirical approach. The study by [11] has most in common with this study in terms of methodology although they use more financial based measures rather than the economic measures used here. They apply a VAR model to primarily investigate the relationship between the stock prices of RE firms, oil prices and technology stock prices. They find that oil prices and technology stock prices can affect RE stock prices. A further set of studies have analysed the ability of various models to forecast the diffusion of RE provision. There are a number of approaches used, such as [12], who use an extended logistic growth model to predict the diffusion of RE in South Korea based on oil prices and policy instruments. Their results suggest that higher oil prices have led to an increase in diffusion rates of RE resources in the electrical power sector. In addition, a further area of the literature analyses the policy and market impacts on the RE market. This includes [13] who develop a model that accounts for the fact that larger companies can have a significant impact on prices in the RE market and find that environmental uncertainties need to be modelled explicitly. Table 1 provides a review of the most relevant studies, which contain measures of RE, NRE (including oil prices), and GDP as well as other macroeconomic variables. Although most compare the causal relationship between RE and GDP and NRE and GDP separately, other studies have analysed the causal relationship between all the variables. Although the results tend to be mixed, many find like this study that the results are heterogeneous across countries, hence the need to analyse the relationship on a country by country basis.

Table 1. Review of the recent literature.

Study	Methodology	Time period	Countries	Results
Sadorsky [3]	Panel cointegration	1994-2003	18 emerging economies	Oil prices→ RE
Payne [14]	Toda-Yamamota Causality	1949-2006	US	No Causality between RE, NRE and GDP.
Bowden and Payne [15]	Toda-Yamamoto causality	1949-2006	US (sectoral)	No causality over RE sectors and GDP.
Menegaki [16]	Random effects panel model	1997-2007	27 European nations	RE but not energy cons positively affect GDP.
Tiwari [17]	PVAR Model	1965-2009	European and Eurasian nations	RE positively affects GDP.
Apergis and Payne [18]	Panel cointegration and Error Correction Models	1980-2011	25 OECD countries	RE ↔ Oil price
Apergis and Payne [19]	Non-linear smooth transition panel vector ECM	1980-2010	7 Central American countries	Oil price →RE.
Apergis and Payne [9]	Panel cointegration and ECM	1990-2007	80 countries	RE↔NRE
Tugcu *et al* [20]	Mulitvariate panel approach	1980-2009	G7 Countries	Results vary across countries
Dogan [21]	Cointegration and causality	1988-2012	Turkey	No causality between RE and NRE

Bhattacharaya *et al.* [4]	Panel causality model.	1991-2012	38 countries	No causality between RE and GDP

Notes: RE is renewable energy, NRE is non-renewable energy, energy cons. is total energy consumption.

Many of the empirical studies have confirmed that increasing oil prices should stimulate greater demand and supply of RE however this paper investigates the sensitivity of RE investment to changes in oil prices, GDP and the interest rate ([22, 23]). Finally, we would expect the three countries analysed to respond in different ways to an oil price shock, from the perspective of RE investment and related policies. This will enable us to determine if the investment of RE is market determined such that it moves in the same direction to oil prices, or is being stimulated by the use of policies which aim to encourage increased production of energy from renewable resources. Policy makers explicitly need to understand how oil prices and macroeconomic variables impact on RE investment.

Following the introduction, this study analyses the background into RE in the three countries investigated, following this we assess the data and results and finally we conclude with a discussion of the policy implications of the study.

2. Country Background and Policies

The paper focuses on individual country analysis, as the relationship between RE, oil prices and other macrocosmic variables is likely to vary substantially across countries, depending on whether the country is a net oil-exporter or importer, its policies towards encouraging RE and its overall wealth. Different countries have adopted different policies to encouraging increased provision of RE resources, as shown by [24] there are a wide variety of different policies available to the authorities to encourage greater use of RE, from fiscal incentives to market based financial policies. The countries analysed are Norway, the UK and USA as they include predominantly net-exporters and importers of oil and have differing policy approaches regarding subsidies and taxes to the RE sector. Additionally, it includes the USA which is the largest economy as well as Norway which is one of the per capita income wealthiest economies in the world, whilst the UK has one of the most well established renewable sectors. Furthermore, they have a relatively long time series of data due to their interest in RE over a prolonged time period.

2.1. Norway

Norway is unique in the world in being a major oil-exporter and also an early champion of RE. It is also one of the wealthiest countries in the world in terms of per capita GDP. Norway is simultaneously the fourteenth largest oil producer and seventh largest RE producer in the world (Central Intelligence Agency and Eurostat respectively), for instance over 100% of Norway's electricity requirements are met by RE, so it is able to export electricity as well as oil. Norway may therefore already have a hedge against oil price fluctuations. If the oil price increases but RE remains constant, then Norway can meet more of its energy obligations using RE rather than oil, and vice versa if the oil price decreases.

Through decades of revenue from oil, Norway has the largest sovereign/pension fund in the world (GPFG), and so has a buffer against any short term oil fluctuations, this is of vital importance to Norway since oil and gas contributes more than 30% of Norway's GDP [25]. The pension fund means that in an economic downturn resulting from a loss of oil revenue there are alternative sources of wealth, rather than debt, although current regulation that the government cannot withdraw more than 4% value of the fund per year restricts how effective this method can be [26]. Norway has considered using the GPFG as a hedge itself against oil price changes through divesting out of fossil fuels, although it is not, for the time being however, pursuing this opportunity.

Although Norway is a major exporter of RE, domestic RE supply as a percentage of total primary energy supply is consistently between 40% and 50%, and the overwhelming majority of this comes from hydropower [27]. Norway has the largest share of RE of any IEA member country and most of the RE supply has been without substantial subsidies, which is in contrast to many other countries, this is almost entirely because of its cost-competitive hydroelectric operations [27]. In 2012 Norway and Sweden jointly introduced a green energy certificate scheme, which was a market based incentive scheme to encourage more investment in RE, however in 2016 Norway left this scheme as it was felt to be undermining the hydroelectric producers of electricity.

Overall therefore, whilst at first glance it may look like the question of 'How will the price of oil affect investment into RE' is obvious for Norway, with its reliance on oil, it actually may be better suited to deal with oil price changes than other countries, so the relationship between oil prices and the RE sector may not be as apparent as in other countries.

2.2. The UK

Whilst, historically a large net-exporter of oil, since 2005 the UK has been a net-importer of oil. With the fall in the oil price from highs of $107 in June 2014 to $40 in November 2015 this has hit North Sea oil production hard, the UK has the highest oil production costs of any major oil producing country in the world at about $40 a barrel, compared to the Middle East, where oil can be produced for as little as $5 [28]. This change in oil prices has had contrasting effects on the UK, North Sea oil production has been hit, but the UK has also had an economic upturn from the lower oil import prices.

The UK has been an advocate of RE production both in the UK and in the wider world, between 2010 and 2014 RE sources more than doubled the proportion of electricity they provided in the UK, to almost 20%. This RE comes from a variety of sources including wind, hydro and bioenergy. Investment into RE has unsurprisingly mimicked this increase in production, also more than doubling between 2010 and 2014 [29]. The UK has also used various incentives schemes to encourage the production and use of RE, including subsidies and the taxing of NRE sources, although recently the levels of subsidy have been reduced. For instance, subsidies for domestic solar power under the Green Deal have been more than halved. The RE policies in the UK have proven to be controversial in some ways, for instance [30] have suggested that to meet the UK's RE targets, they will require a large amount of biomass, requiring substantial imports to meet these demands. They suggest this could have negative environmental externalities in the form of deforestation and food supply.

2.3. The USA

The United States' experience with oil is the reverse of the UK, having been a net-importer of oil since the 1940s, then in 2013 the USA became a net-exporter of oil again and now is the world's largest producer (not the largest exporter however, due to large domestic demand for oil and restrictions on the legality of exporting oil [31]). The reason for this huge increase in oil production is in a large part due to fracking, a method of firing a high-pressure water mixture at shale rock in order to release gas and oil from the rock, which is a cost effective way to produce oil and gas.

Alongside this increase in oil production, RE investment and production has also increased in recent years, contributing 13.4% of domestically produced electricity in 2015 [1]. There is little reliable data on levels of subsides for RE across these countries, as what constitutes a subsidy can be controversial. The Financial Times used IEA data and found that the USA has about $15.4 billion of subsidy, whereas the UK, has about $4.1 billion. In terms of subsidy relative to country GDP, the UK has approaching twice the level of subsidies to the USA in 2013 overall. Investment has increased proportionally with this increase in renewable production and has largely been supported to an extent by state and federal-level support as well as increased efficiency and potential returns from renewable investments.

A feature of the USA that affects how the price of oil impacts the economy is that the benefit resulting from oil price increases can vary substantially from state to state depending on whether they are oil-importing or exporting states. Whilst overall for the USA the decrease in the price of oil from 2014 has been seen as broadly positive in economic terms, there are substantial regional differences in the effects it has, and therefore the effect the oil price will have on renewable investment also [32].

3. Renewable Energy Model

There is no specific theoretical model to explain this relationship between RE investment and the macroeconomy as is typical when conducting a VAR analysis, However, based on a standard accelerator approach to investment, output growth is an important determinant and according to Keynesian investment theory, investment decisions depend on the relationship between the marginal efficiency of capital and interest rates, producing an inverse relationship between investment and interest rates. In addition, for the energy sector it is important to incorporate the price of the main substitute in the form of oil prices, giving a model consisting of real oil prices (ROIL), output growth and the interest rate as factors that can affect renewable energy investment (REI). This choice of variables in the VAR also reflects the previous research in this area, such as [3], [33] [8], [11] and [34].This produces the following empirical relationship:

$$REI = f(ROIL, RGDP, INTR) \tag{1}$$

Furthermore with regard to the specifics of the relationships, to account for changes in wealth we have included real gross domestic product (RGDP), in general wealthier countries are more likely to invest in cleaner energy production, so we would expect a positive relationship between GDP and RE production. Although investment in RE and GDP have not been directly analysed as yet, [35] showed that in the long-run and short-run there is a positive relationship between economic growth and general RE investment. Granger causality tests have produced mixed results regarding causality between economic growth and investment, with some evidence of bi-causality. They further suggested that government policies should be encouraged in order to enhance the expansion of the RE sector. Economic growth can cause investment through rising wealth increasing the ability of governments to spend on infrastructure, raising the marginal productivity of labour, which encourages investment. [3] and [6] have already found evidence of the bi-causality between economic growth and RE across emerging economies. The interest rate (INTR) is also included as it accounts for the monetary side of the economy, for instance [11] has found that variation in RE consumption is explained by past movements of the interest rate. [3] and [33] identifies a significant relationship between the stock prices of RE based producers (which in turn influences investment) and interest rates. Finally, oil prices (oil) have been introduced into the model, reflecting its role as a substitute for RE, such that as oil prices rise, it becomes more cost effective to invest in and produce RE. Furthermore, oil is the main competitor of renewables in some specific countries ([36]). However as mentioned this relationship will depend on whether the country is an oil-exporter or oil-importer among other factors. We would expect oil-importers to have a closer relationship between RE and oil prices, as due to energy security factors they are more likely to feel the need to increase production of non-oil based energy, when oil is scarce and prices rise. Many studies indicated that an oil price increase has a positive impact on the RE investment in oil-importing countries ([8, 37, 11, 38, 39]). As noted earlier over most of the sample analysed, Norway and the UK are net oil-producers whilst the US is a net oil-importer, so we would expect a closer relationship between oil prices and RE investment in the USA.

3.1. Methodology

To assess the response of RE investment to the real oil price, real GDP and interest rate shocks, this study employs an unrestricted VAR model (proposed by [2]). The VAR Model gives a multivariate approach where changes in a particular variable are dependent on its own lags and the lags of other variables (see [40]). The VAR considers all variables as jointly endogenous and does not impose any *a priori* restrictions on the structural equations.

The VAR model is specified as $$z_t = \alpha + \sum_{j=1}^{p} \beta_j z_{t-j} + u_t \tag{2}$$

where $z_t = [\Delta REI_t \quad \Delta ROIL_t \quad \Delta RGDP_t \quad \Delta INTR_t]'$ is a vector of endogenous variables at time t, $\alpha = (\alpha_1, \ldots, \alpha_4)'$ is the (4x1) is a vector of constants, β_j is the j[th] (4x4) matrix of AR coefficients for j=1,2…p and $u_t = (u_{1t}, \ldots, u_{4t})'$ is the (4x1) vector of error terms. The DREI, DOIL, DRGDP and INTR are the first differences of renewable energy investment (REI), real oil price (ROIL), Real GDP and interest rate (INTR) respectively. The form of the unrestricted VAR model can be specified as;

$$\begin{bmatrix} \Delta REI_t \\ \Delta ROIL_t \\ \Delta RGDP_t \\ \Delta INTR_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{bmatrix} + \beta(L) \begin{bmatrix} \Delta REI_t \\ \Delta ROIL_t \\ \Delta RGDP_t \\ \Delta INTR_t \end{bmatrix} + \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \\ u_{4t} \end{bmatrix} \tag{3}$$

where $\beta(L)$ is the lag polynomial operator, the error term vectors are expected to be zero mean and uncorrelated. The dynamic response of RE to shocks in the macroeconomic variables or oil price can be traced using the generalized impulse response functions (GIRFs). The GIRF, introduced by [41] and [42]), takes the traditional distribution of the residuals into account and computes the dynamic response to the reduced form shocks in the VAR. This approach entails no identification restrictions and is unaffected by the ordering of variables when computing the impulse responses. The forecast error variance decomposition has also been estimated in order to explain the relative contribution of an individual variable to the variance of REI.

4. Data and Results

The date used is annual and consists of RE investment, real (inflation-adjusted) oil prices, real GDP, and the interest rate covering the period 1960-2015. The data has been taken from the International Energy Agency (IEA), International Financial Statistics (IFS), Federal Reserve Bank of St. Louis, OECD database Edition: May 2017. The real Gross Domestic Product (GDP) series is GDP at constant prices (Units: National Currency; Scale: Billions). The nominal oil price series is the petroleum average crude price (Units: USA Dollars per Barrel). The real oil price is computed from the nominal oil price deflated by the implicit consumer price index of the USA, to account for high inflation during the 1970s and 1980s. The interest rate is defined as the government long-term bond yield. The data was limited to annual data as higher frequency data for RE is not available for an extended period of time for Norway and the UK. The paper uses the RE generation as a proxy for RE investment, as they are highly related series, in that as soon as installed the RE is relatively costless to produce. The reason for using RE generation data rather than using installed capacity is that the data availability for installed capacity is only available since 1990, whereas generation figures have been available since 1960. Whilst there is not a perfect correlation between the two, between 1990 and 2015 for the three countries selected correlation coefficients between generation and installed capacity were positive, above 0.5 and significant, especially when considering this is a truncated set of data compared to the dataset used, with values of 0.66, 0.91 and 0.74 for Norway, the UK and US respectively and all are significant at the 1% level. All the data is in logarithmic form (except the interest rate).

To begin with we test for a unit root in all the variables, as a preliminary analysis, we apply the standard linear Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) tests. As a further test we have conducted the unit root tests of Ng and Perron [43] with a structural break. These tests are modified versions of the existing unit root tests, but with a better performance in terms of power and size distortions. Ng and Perron introduced a set of four unit root tests, namely MZa, MZt MBS and MPT. The number of lags used to compute the tests has been chosen using the modified AIC (MAIC) proposed by [43]. Table A1 in the appendix presents unit root test results together with the corresponding critical values. Being in line with the other studies, the findings confirm that all four series are stationary in first differenced form for each country at the 5% significance level. The results are similar to both the conventional without structural breaks and with structural breaks unit root tests.

As all the variables are I(1), we next need to test for cointegration. We have used the Johansen Maximum Likelihood Procedure and Engle-Granger cointegration methods, both including a constant but no trend and the results are reported in the Appendix Table A2. The study also finds that there was no threshold (asymmetric) cointegration[4]**.** As there is no evidence of cointegration, there is no long-run equilibrium relationship, so we have not formed the VECM, instead a VAR is used, with all the variables in first-difference form, including RE, real GDP, real oil prices and the interest rate. furthermore, to control for the oil price shocks of 1973-74 in all the countries and for the 2008 UK financial crisis as well as the 1990 Iraq war, we have employed dummy variables as exogenous variables in the VAR estimation. Table 2 reports VAR estimation and diagnostic tests, for all countries the optimal lag selected by the Akaike and Bayesian Information Criteria indicates 1 lag for Norway and the UK and 4 lags for the USA. No root lies outside the unit circle and the VAR satisfies the stability conditions for all the countries. Column 4 has the values of the LM tests for autocorrelation along with the corresponding p-values, indicating that there is no autocorrelation in any of the models. Overall, there are no significant outliers left unmodelled and we consider the estimates satisfactory.

[4] Results are available on request.

Given the above results, we are able to use the VAR with first-differenced data to ensure the variables and residuals are stationary. There is some variety across the p-values in terms of the Jarque-Bera test, the USA has most evidence of normality in the residual due to its greater macroeconomic size, relative to the UK and Norway. But as the VAR is stable this isn't a problem for the estimation.

Table 2. Summary of the VAR estimations and diagnostic tests

Country	N	*VAR*-lag	Root	LM Test P-value	Jarque-Bera, p-values				
					Rew	Oil	GDP	Interest	Joint
Norway	55	1	0.221	0.967	0.267	0.000	0.826	0.001	0.000
UK	55	1	0.155	0.424	0.000	0.050	0.002	0.835	0.000
USA	55	4	0.577	0.760	0.585	0.989	0.015	0.917	0.203

Note: Table contains p-values for the Jarque-Bera and LM tests. The p-value represents levels of the marginal significance relating to a statistical hypothesis test, measuring the probability of an event occurring.

Firstly, Granger causality is computed using LA-VAR Wald tests, where the lag length is based on the Akaike and Bayesian + 1 criteria. (see [44]), indicating that RE is explained by past movements in oil prices and GDP in the USA, but interest rates do not Granger-cause RE (Appendix Table A3). These results partially support [14] although in that study over a different time period for the USA, there is no evidence of causality between oil prices and RE in the long-run. For Norway, the RE is influenced by the lagged GDP and lagged interest rates. Since interest rates are a lagging economic indicator, this result is consistent with the view that increased economic growth leads to higher interest rates. Neither GDP, nor oil prices have a Granger causal impact on RE in the UK. However, real oil prices, GDP and the interest rate jointly Granger-cause RE investment in Norway and the USA. This suggests that these variables jointly determine the RE investment and supports the conjecture that these are the relevant factors driving the renewable market.

To analyse the effects of a shock to real oil prices and its effect on RE, the GIRFs are used in Fig. 1. For robustness, we also computed Cholesky one standard deviation impulse responses in addition to the use of generalised impulse responses, the findings were similar using both approaches[5]. In the impulse response functions, the dashed lines show a one standard error 95% confidence band around the estimates of the coefficients of the impulse response functions. For Norway and the USA, the structural shocks to oil prices have a significantly positive effect on RE, whereas in the UK the effect is not significant. The oil price shocks have, as expected, a positive and highly significant effect on RE in the oil-importing country, the USA, where RE investment increases by about 3% after the one standard deviation shock. This is consistent with the findings, reported by [11], [45], [46] and [47], who find that there is a significant impact of oil prices on RE. For Norway there is a significant and positive relationship between oil prices and RE, reflecting the market orientated approach to the sector in Norway. However, the oil price shocks have a negative and negligible effect on RE in the UK, the effect is very small and became zero after 3 lags. This may be because the UK has been an oil-exporter for most of the period studied and oil price shocks have had little effect on investment in the renewable sector. Furthermore, this could be due to greater intervention in the UK market in the form of subsidies by the authorities as noted in section two earlier. Due to the lack of any significant effect in the UK, we further computed a non-linear VAR for the UK to analyse the asymmetric effect of oil prices on RE investment, by using the approach of [48], Mork defines positive and negative annual OP innovations as $\Delta \mathrm{ROIL}_t^+$ and $\Delta \mathrm{ROIL}_t^-$ respectively, in the following ways;

$$\Delta \mathrm{ROIL}_t^+ = \max\left[0, \left(\mathrm{ROIL}_t - \mathrm{ROIL}_{t-1}\right)\right] \tag{4}$$

[5] Results are available on request.

$$\Delta ROIL_t^- = \min[0, (ROIL_t - ROIL_{t-1})] \quad (5)$$

The findings of the non-linear model parallel the linear model regarding the negligibility and insignificant impact of oil price shocks on RE. However, the magnitude of the response is higher in the non-linear model as compared to the linear model, the results are reported in Appendix Fig. A1.These results indicate that there are no symmetric or asymmetric effects from oil price shocks on the UK's RE investment. In addition to the high levels of support for RE in the UK, a further possible explanation for these results is as follows. As suggested by [49] the primary objective of the UK energy policy is to ensure a reliable supply to the residential market to prevent fuel poverty, to reduce carbon emissions and to increase revenue, so the UK RE sector is not as sensitive to oil prices. Therefore, when the oil price increases and decreases, it has had little direct impact on the UK renewable energy sector due to the extensive financial support available to those wishing to invest in the renewable energy sector during the period analysed.

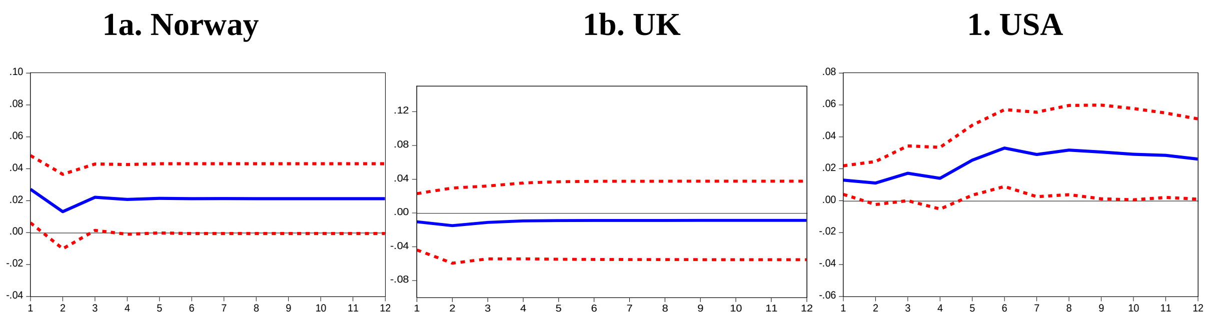

Fig. 1. Renewable energy response to real oil price shocks.

Output (productivity) shocks have positive effects on RE, which causes an increase in RE investment in all countries except the UK as reported in Fig. 2. This parallels the findings of [5], [6] and that economic growth has a positive and statistically significant impact on RE. However, the response of RE to output shocks is insignificant in the UK and USA. For Norway, the response of RE to a real GDP shock is significantly positive and permanent reflecting that it is more market orientated in this country.

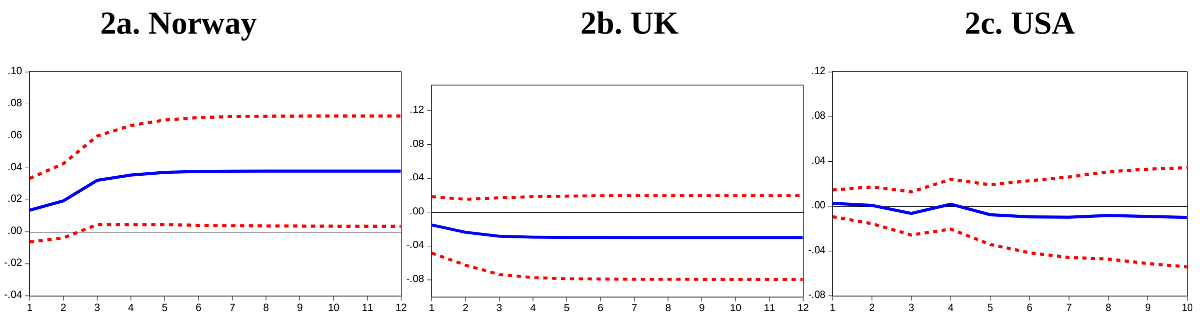

Fig. 2. Renewable energy response to GDP shocks.

Fig. 3 shows that the monetary shocks have an insignificant effect on RE in all countries. The finding is consistent with [11] as they find a negligible response of RE to an interest rate shock.

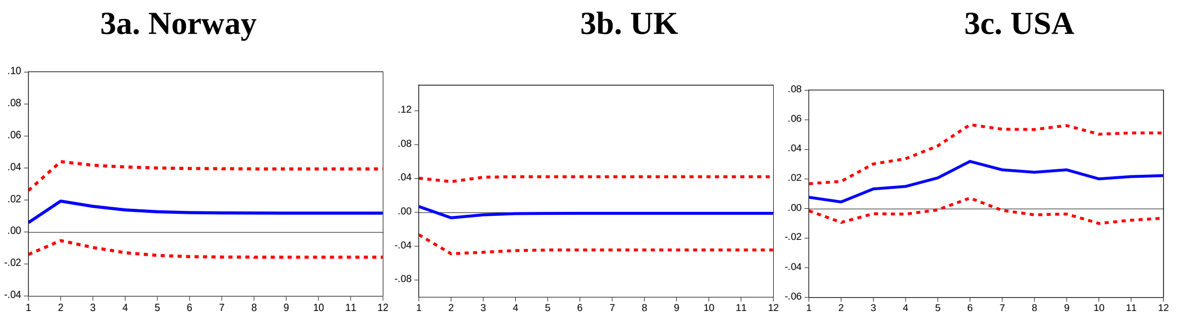

Fig. 3. Renewable energy response to interest rate shocks.

We further do some robustness checks on these baseline results. We use nominal oil prices instead of real oil prices in eq. (3) as suggested by [50, 51] and [10]. For simplicity, we only report the results corresponding to RE investment to oil price shocks, which are reported in Fig. 4. We find that the empirical results are almost identical to the corresponding baseline results with nominal prices.

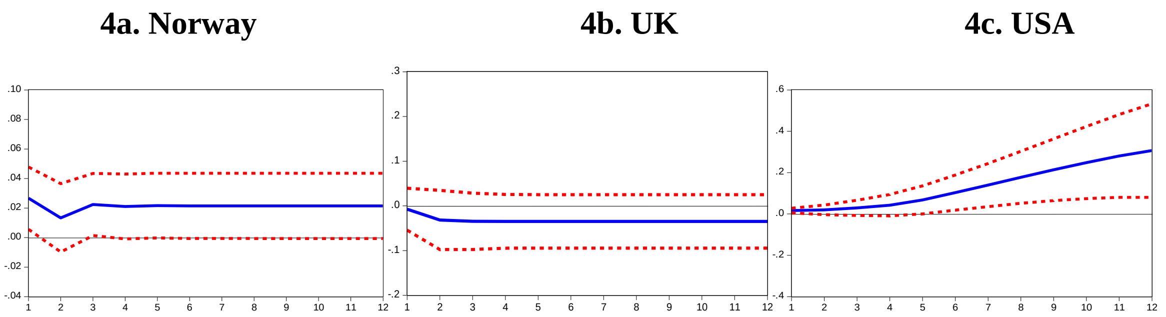

Fig. 4. Renewable energy response to nominal oil price shocks.

The forecast error variance decomposition is used to measure the proportion of variations in RE investment caused by oil prices, output and interest rate shocks respectively. The results are slightly different to the IRFs, as oil prices tend to only explain a small amount of the RE variance, with the exception of the USA. In this case after 12 time periods, 22% of the variance is explained by oil prices, as reported in Table 5. In Norway it is approximately 4% and for the UK only about 3%, see Table 3 and 4. For the latter countries, it is the RE that explains most of the RE variance, where the forecast error variance of RE to its own shocks are about 88% in Norway and 97% in the UK. Output shocks contribute about 4%, 0.5% and 14% of the changes in RE in Norway, UK and USA respectively. In contrast impulse response, productivity shocks forecast a substantial amount of the variance of the RE in the USA. Monetary (interest rate) shocks contribute 13% of the changes in RE in USA in the long-run. This suggests that only in the USA is there a substantial relationship between RE and oil prices, reflecting the different nature of the USA RE market, which is more market orientated than in other countries, with fewer policies encouraging RE through the tax and subsidy systems. In the UK during the time period investigated, the RE market is subject to more interference by government, with higher levels of subsidy and use of environmental taxes. Norway appears to lie between these two extremes, reflecting the lesser need for the authorities to intervene in the market, as Norway's hydro-electric industry operates in a market environment and doesn't require high levels of subsidies. Overall according to the variance decomposition analysis the strongest response is in the USA, with approximately 22% being explained by the oil price, Norway has a moderate response whereas in the UK it is the poorest.

Table 3. Forecast error variance decompositions of renewable energy Norway.

Horizon	Renewable	Oil Price	Output	Interest Rate
1	100.00	0.00	0.00	0.00
2	91.27	1.57	2.43	4.71
3	87.91	3.53	3.67	4.87
4	87.68	3.54	3.85	4.91

5	87.62	3.54	3.89	4.92
6	87.63	3.54	3.90	4.93
7	87.62	3.54	3.90	4.93
8	87.62	3.54	3.90	4.93
9	87.62	3.54	3.90	4.93
10	87.62	3.54	3.90	4.93
11	87.62	3.54	3.90	4.93
12	87.62	3.54	3.90	4.93

Table 4. Forecast error variance decompositions of renewable energy UK.

Horizon	Renewable	Oil Price	Output	Interest Rate
1	100.00	0.00	0.00	0.00
2	96.82	2.67	0.42	0.09
3	96.74	2.67	0.42	0.17
4	96.70	2.67	0.44	0.18
5	96.70	2.68	0.44	0.18
6	96.70	2.68	0.44	0.18
7	96.70	2.68	0.44	0.18
8	96.70	2.68	0.44	0.18
9	96.70	2.68	0.44	0.18
10	96.70	2.68	0.44	0.18
11	96.70	2.68	0.44	0.18
12	96.70	2.68	0.44	0.18

Table 5. Forecast error variance decompositions of renewable energy USA.

Horizon	Renewable	Oil Price	Output	Interest Rate
1	84.85	15.15	0.00	0.00
2	83.88	15.22	0.27	0.61
3	71.65	15.74	6.58	6.02
4	67.22	15.45	11.34	5.98
5	58.82	21.09	14.47	5.61
6	54.17	22.41	13.54	9.87
7	52.70	22.65	13.73	10.91
8	52.66	22.68	13.70	10.95
9	52.43	22.66	13.79	11.11
10	51.61	22.28	13.51	12.59
11	51.34	22.19	13.74	12.72
12	51.14	22.37	13.73	12.76

5. Discussion and policy analysis

5.1. Discussion

This study has shown the importance of considering the movements in oil prices when developing policies to encourage greater use of RE markets. This is particularly important given the recent volatility in the oil markets. In particular, it emphasises the need to consider these policies on a country by country basis, with regard for whether the country imports or exports oil and the financial support available for the renewable sector. As [36] has indicated one of the key variables for encouraging investment into the RE market is ensuring there is a sufficient market based return from the investment, whilst accounting for any financial support a specific country may be providing to the sector. As they note this tends to depend on the main competitors to RE which tends to be oil. So the return is highly sensitive to movements in oil prices in those economies where the RE sector is more market orientated. However, in countries where there is more intervention in the renewable sector, this return is less sensitive to oil market volatility. This suggests that future investment in the renewable sector needs to consider not only the local market for energy but also potential movements in oil prices when deciding on whether to invest or not.

5.2. Policy implications

These results from the VAR analysis show just how important government policy has been in mapping the course of renewable investment, especially for the UK, although of less importance in the USA. This was a common theme in the literature but was often assumed rather than quantitatively suggested. It also seems that traditional determinants of investment in general, such as GDP growth, can only go part of the way towards explaining renewable investment, there must be other determinants that can better explain changes in renewable investment, i.e. government intervention. Recently government spending in renewables has fallen, and with costs of renewables now a fraction of what they were in the past, in future the VAR model should be able to better show which macroeconomic factors determine RE investment.

There are a number of important policy implications resulting from this study, with regard to energy policies which aim to reduce carbon emissions whilst encouraging the RE sector to become more market orientated. As noted, the evidence suggests the RE markets are fundamentally different across countries, depending on whether the country is a net-exporter or importer of oil, the approach of the authorities to supporting RE, the extent to which the geography of a country supports RE as in Norway and the wealth of a country. Where a country has a more market orientated energy sector as well as being a net-importer of oil, as in the USA, the RE industry has a strong relationship with the oil market. However, in countries such as the UK, where until recently there was a comprehensive policy framework of support for the renewable sector, investment and therefore production of energy from renewables will be less sensitive to movements in the oil market. Given recent volatility in the oil market and recent falls in support for RE, it could be worthwhile designing policies that take into account the need to smooth investment and production in the renewable sector throughout the oil cycle, in the future.

In general, a more counter-cyclical approach might be required regarding energy policies, which are associated with the price of oil. The recent sharp decline in the price of oil has caused the potential for disruption in investment in renewables, to the extent that they could decline and become insufficiently profitable. With respect to oil prices, there is now an opportunity for policy makers in countries that subsidies the price of oil to decrease subsidies on oil prices, when the price falls so as to ensure renewable energy remains profitable. For countries where such large subsidies don’t exist, policy makers could raise taxes on oil prices. This would minimise the oil price fall’s negative effects on RE investment. Hence when the oil price declines then either taxes could rise or subsidies could be decreased. Any increase in tax revenue or fall in public spending could be utilised to subsidise renewables, and/or develop them and also offer support for poor consumers adversely affected by those changes. In contrast, when the oil price increases, taxes on them could be lowered. In particular, for the USA and Norway, where RE is more sensitive to oil price changes, these policies could be considered, especially during the current rea of relatively low oil prices.

A further policy implication of this study relates to the hedging role of renewable energy, as initially discussed by [52] This study suggests that the policy mix in terms of RE and NRE, could provide a useful hedge against the negative effects stemming from volatility and unpredictability in the oil price. This study indicates that if fossil fuels are the only sector of the market that is exposed to volatility in the commodity markets, then increasing the proportion of renewable energy in the mix will reduce the overall volatility of the portfolio of energy sources volatility. This study supports this proposition but emphasises that this policy would only work in some countries where the relationship between renewable energy and oil markets is minimal.

5.3. Future research and limitations

Future research needs to take into account that the world of RE has changed over the past few years, with reductions in the levels of financial support and this trend will continue in the future, so future economic analysis surrounding it will need to reflect these changes, including the impact of increased demands for cleaner fuels and a less polluted environment. In addition, future research will need to take into account some of the negative externalities associated with RE, such as the impact on the environment of increased use of biomass. This study has taken advantage of the recent availability of sufficient data to conduct a time series analysis, however as is common with this type of study it would have benefited from a longer time series.

6. Conclusions

This paper has analysed the interrelationship between RE investment and oil prices along with the main macroeconomic factors, providing a quantitative analysis of a topic hitherto mainly qualitatively discussed. Granger causality tests indicate that movements in oil prices, GDP, and interest rates each have a relatively strong power in explaining the movements of the RE sector, except in the UK where the impact is poor. The results show oil prices have a significant impact on the RE sector in Norway and particularly strongly in the USA. The results also suggest that GDP and interest rate shocks have moderately positive and significant effects on RE investment in Norway. For Norway the impulse responses are moderate, showing that it lies between the USA and UK, which has poor effects, in that there are significant effects from oil prices and GDP on the renewable sector, although the effect is not so strong based on the variance decompositions. The variance decomposition shows the oil price explained a significant part, approximately 22% of the variance of RE investment in the USA. In contrast to the impulse responses, GDP growth and interest rates explained a substantial part of the forecast error variance of RE in USA showing that RE investment is sensitive in these countries to the costs of borrowing. Overall these results support those of some previous studies such as [20] that found the relationship between the renewable energy sector and the macroeconomy, including non-renewable energy markets, varies substantially across countries and is therefore better modelled on an individual country basis.

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Appendix

a. Positive change in OP **b. Negative change in OP**

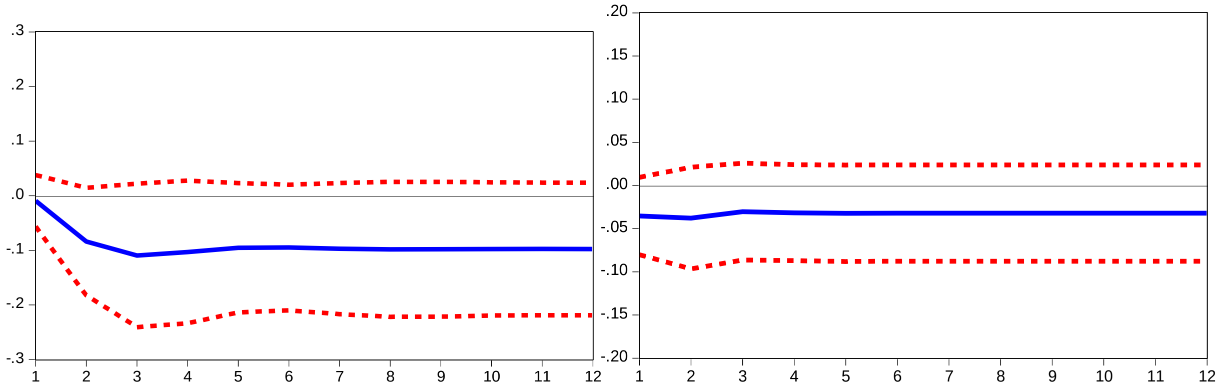

Fig. A. Asymmetric response of renewable energy to real oil price (OP) shock for UK.

Table A1. Unit root test results.

Variables		ADF	PP	MZ_{α}^{GLS}	MZ_{t}^{GLS}	MSB^{GLS}	MP_{T}^{GLS}
	Norway						
Renewable	Level	-2.94	-2.62	-1.76	-0.77	0.44	39.43
	1st difference	-6.38*	-14.52*	-20.13*	-3.16*	0.16*	4.56*
Real Oil Price	Level	-1.89	-1.99	-6.66	-1.79	0.27	13.70
	1st difference	-7.18*	-7.17*	-26.86*	-3.45*	0.13	1.57*
Real GDP	Level	-0.27	-0.22	-2.07	-0.71	0.34	28.48
	1st difference	-4.53*	-4.87*	-26.98*	-3.67*	0.14*	3.39*
Interest Rate	Level	-0.89	-0.97	-1.10	-0.56	0.51	54.23
	1st difference	-5.62*	-5.60*	-26.15*	-3.61*	0.14*	3.51*
	UK						
Renewable	Level	-1.38	-1.20	-2.37	-0.90	0.38	30.86
	1st difference	-8.44*	-8.68*	-26.74*	-3.65*	0.14*	3.41*
Real Oil Price	Level	-1.89	-1.99	-6.66	-1.79	0.28	13.70
	1st difference	-7.18*	-7.17*	-26.86*	-3.45*	0.13*	1.57*
Real GDP	Level	-0.46	-0.50	-0.46	-0.18	0.39	39.73
	1st difference	-5.24*	-4.94*	-24.54*	-3.50*	0.14*	3.72*
Interest Rate	Level	-1.71	-1.60	-2.01	-0.89	0.54	38.75
	1st difference	-5.92*	-7.52*	-26.06*	-3.61*	014*	3.49*
	USA						
Renewable	Level	-152	-1.61	-3.59	-1.34	0.37	25.38
	1st difference	-7.33*	-7.37*	-26.92*	-3.65*	0.14*	3.51*
Real Oil Price	Level	-1.89	-1.99	-6.66	-1.79	0.27	13.70
	1st difference	-7.18*	-7.17*	-26.86*	-3.45*	0.13*	1.57*
Real GDP	Level	-2.30	-1.52	-6.35	-1.54	0.24	14.32
	1st difference	-5.66	-5.48	-24.83	-3.52	0.14	3.68*
Interest Rate	Level	1.49	-1.55	-2.47	-1.00	0.41	32.63
	1st difference	-6.43*	-6.43*	-26.50*	-3.64*	0.14*	3.44*

Model with constant and linear trend: critical values

	ADF	PP	MZ_{α}^{GLS}	MZ_{t}^{GLS}	MSB^{GLS}	MP_{T}^{GLS}
1%	-4.13	-4.13	-23.80	-3.42	0.14	4.03
5%	-3.49	-3.49	-17.30	-2.91	0.16	5.48
10%	-3.18	-3.18	-14.20	-2.62	0.18	6.67

Note: * indicate the level of significance at the 5%.

Table A2. Cointegration tests results.

Hypothesised No. of CE(s)	Trace Test		Maximum Eigenvalues		Engle-Granger Test	
	Statistics	Critical Values 5%	Statistics	Critical Values 5%	Statistics	Critical Values 5%
Norway						
None	44.80	47.86	21.09	27.58	-2.06	4.22
At most 1	23.70	29.80	12.37	21.13	NA	
UK						
None	33.29	47.86	15.83	27.58	-2.05	4.22
At most 1	17.46	29.80	11.68	21.13	NA	
USA						
None	44.06	47.86	24.02	27.58	-2.27	4.22
At most 1	20.04	29.80	12.20	21.13	NA	

Table A3. Granger causality/block exogeneity Wald tests based on a VAR model.

1: Norway

Null Hypothesis	Chi-square	lag	Prob.
ΔOIL does not Granger cause ΔREW	1.82	2	0.18
ΔGDP does not Granger cause ΔREW	2.39	2	0.12
ΔINTR does not Granger cause ΔREW	3.20	2	0.07
All ΔOIL, ΔGDP and ΔINTR does not Granger cause renewable energy	7.84	2	0.04

2: UK

ΔOIL does not Granger cause ΔREW	1.13	2	0.28
ΔGDP does not Granger cause ΔREW	0.38	2	0.53
ΔINTR does not Granger cause ΔREW	0.06	2	0.80

All ΔOIL, ΔGDP and ΔINTR does not Granger cause renewable energy	1.63	2	0.65
3: USA			
ΔOIL does not Granger cause ΔREW	8.07	5	0.04
ΔGDP does not Granger cause ΔREW	13.26	5	0.01
ΔINTR does not Granger cause ΔREW	7.33	5	0.11
All ΔOIL, ΔGDP and ΔINTR does not Granger cause renewable energy	23.94	5	0.00